Crack growth in shot peened Al 7050 and 7075 alloys

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- The main objective of the research is to determine the growth rates of short cracks through the thin zone of residual stresses created as a result of surface treatments such as shot peening
  - Several specimen types were investigated
    - There is little experimental data in the open literature about fatigue crack growth in materials which are surface treated using shot peening

- Materials currently being investigated
  - 7050 T7451 (0.25 inch thick sheet)
  - 7075 T7351 (0.25 inch thick sheet)
- Specimen types currently being investigated
  - Hour-glass coupons with a surface scratch (representing a machining flaw)
  - Double edge notched specimen with an EDM notch (to be done at Dr. Forman's laboratory)

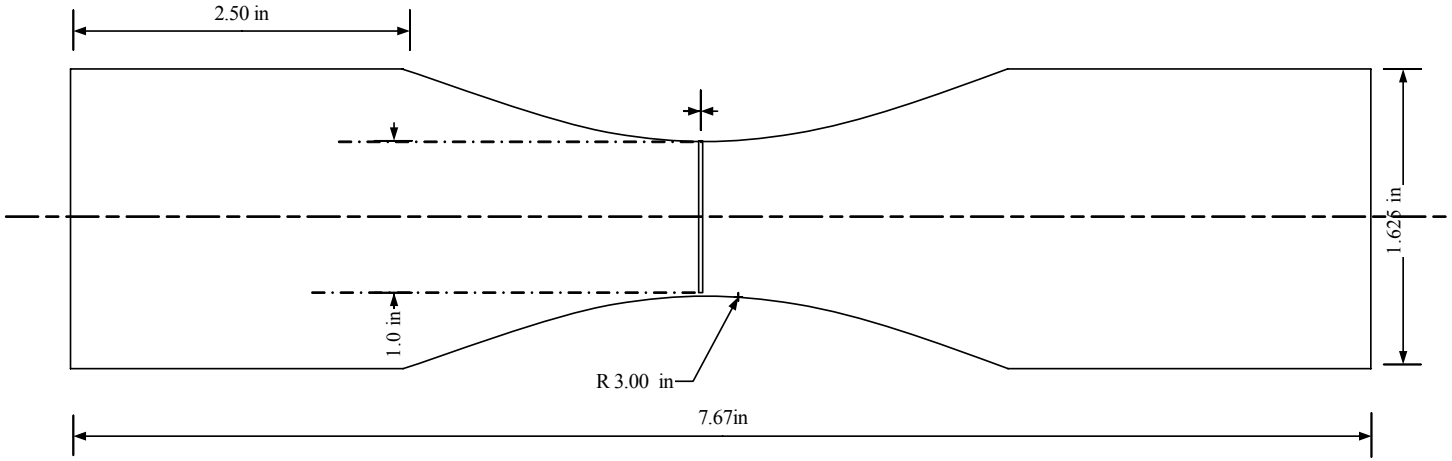
Specimen with a surface scratch

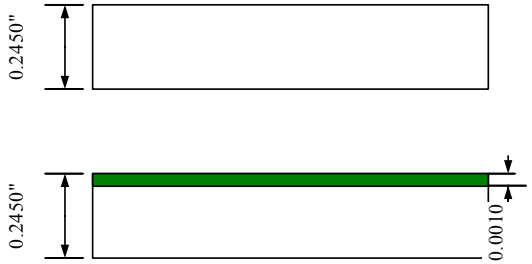
- Determine the effect of shot peening on the fatigue resistance of Al alloys with and without machine like flaws
- The following slides show the hourglass coupon with a scratch at the mid-section of the specimen
  - The second figure shows the details of the scratch
- The specimens were peened on all sides (grip region excluded)

The following measurement techniques were tried

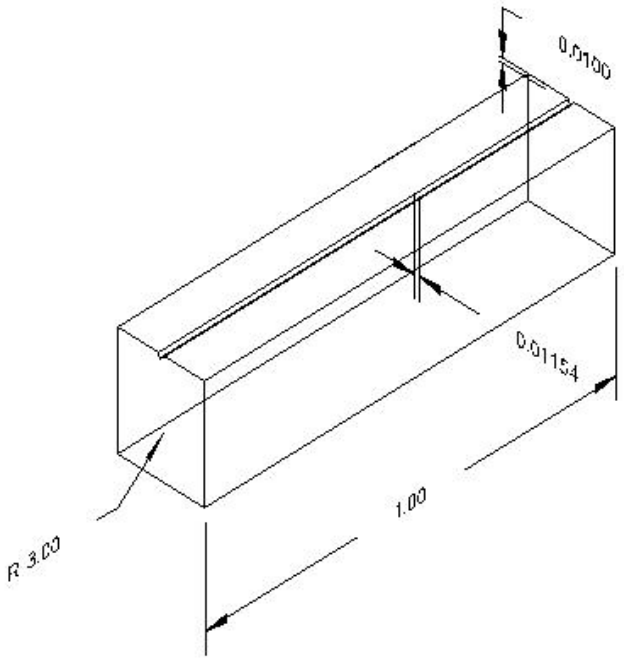
1. The CMOD (measured using a laser extensometer)
2. Use of a stereo microscope to determine the surface crack length
3. Aramis photogrammetry system used to measure the strain field around the notch (scratch)
4. Eddy current probe was used to determine the onset of cracking
5. Laser Speckle method ESPI was used to monitor the displacement field around the notch

Hour-glass specimen with a surface scratch





Details of the surface scratch



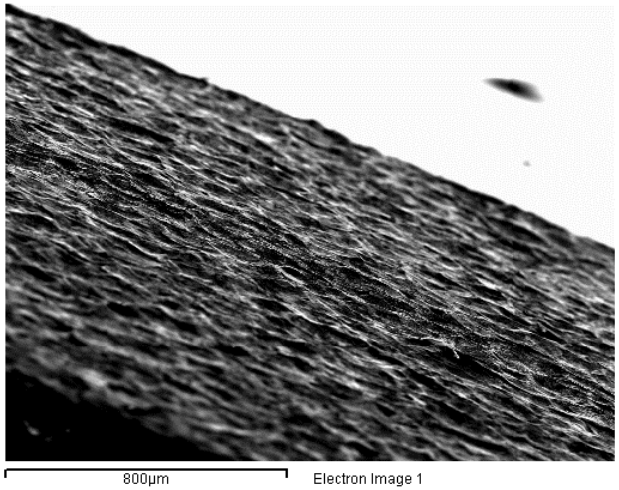
- Initial specimens were manufactured with a scratch of 0.01”
- Specimens with surface scratch depth of 0.0010 ~ 0.0020 inches have been manufactured and shot peened
- Several measurement techniques were utilized

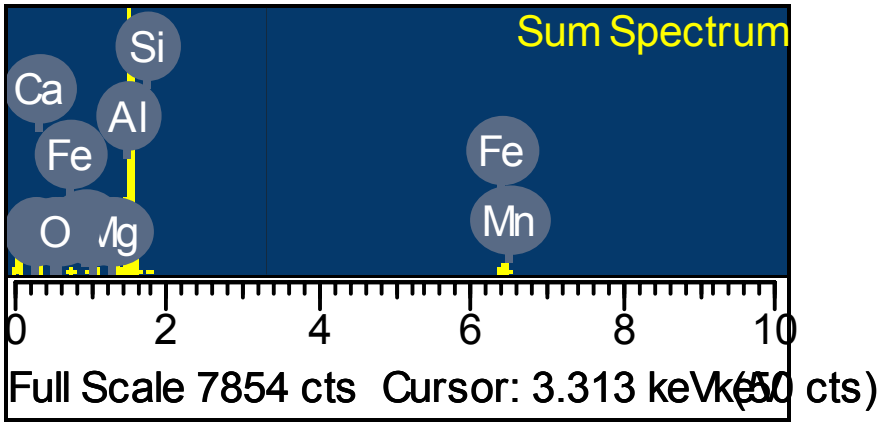
- Different methods tried to detect the onset of cracking
  - Crack detection gages
    - Triggered after the crack had grown under the surface - the crack initiations sites are not exactly at the edges
  - Laser extensometer to monitor the CMOD
    - Very difficult to determine the crack growth from change in compliance and unable to resolve the cause of noise in the measurement
  - Use of Aramis photogrammetry system to monitor the displacement field around the scratch
  - ESPI (Laser Interferometer) method
  - Use the eddy current probes to detect the onset of cracking
    - Difficult as there is presence of iron from the shot peening on the surface
  - Developing a probe to measure the ACPD to monitor crack initiation and growth in the hourglass coupons

Surface Characterization

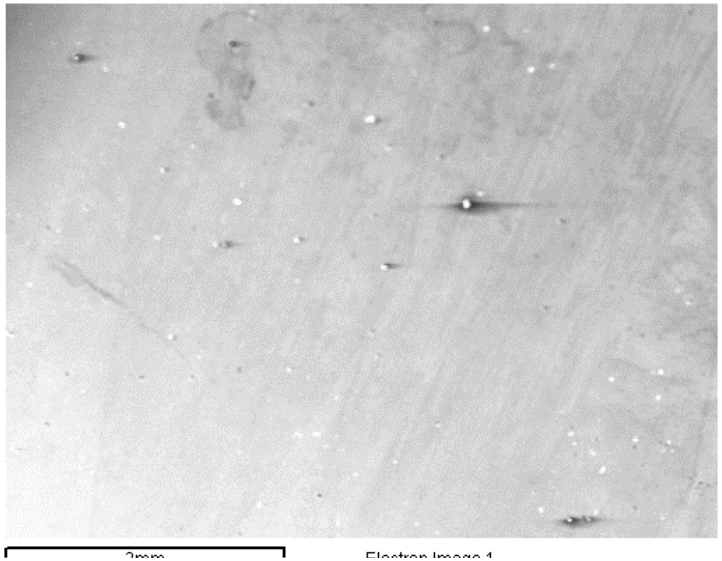
- The surfaces were examined at a magnification of 20 to 100X
- EDS analysis was conducted on the shot peened and the electro polished surfaces
  - Confirmed presence of iron residue from the shot peening process
  - The presence of the iron interferes with the eddy current probe reading causing spurious peaks making it difficult to predict the onset of cracking

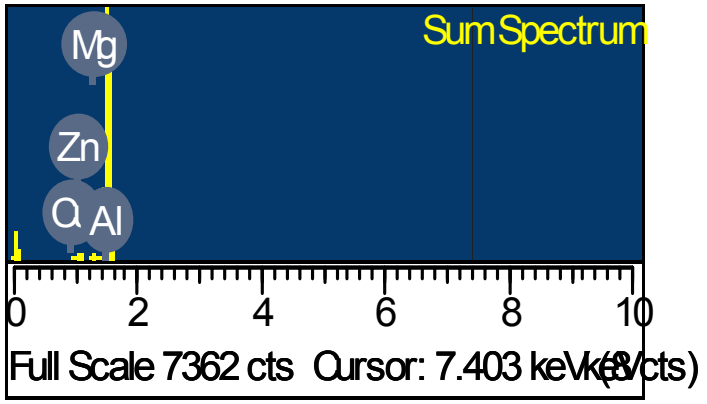
EDS analysis of the surface



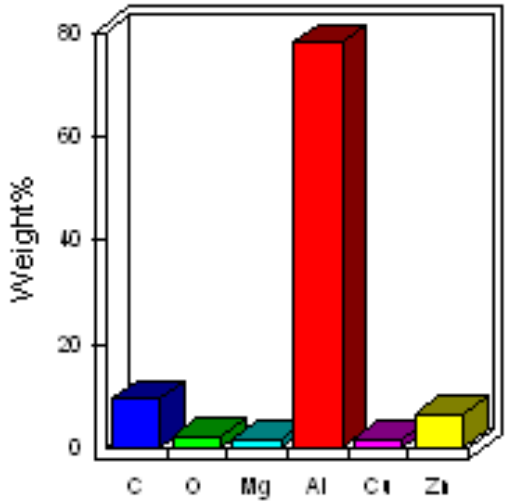


Element	Weight%	Atomic%
C K	29.17	44.32
O K	25.84	29.47
Mg K	2.10	1.58
Al K	30.17	20.41
Si K	0.64	0.41
Cl K	0.18	0.09
Ca K	0.17	0.08
Mn K	0.19	0.06
Fe K	7.15	2.34
Cu K	1.18	0.34
Zn K	3.21	0.89
Totals	100.00	





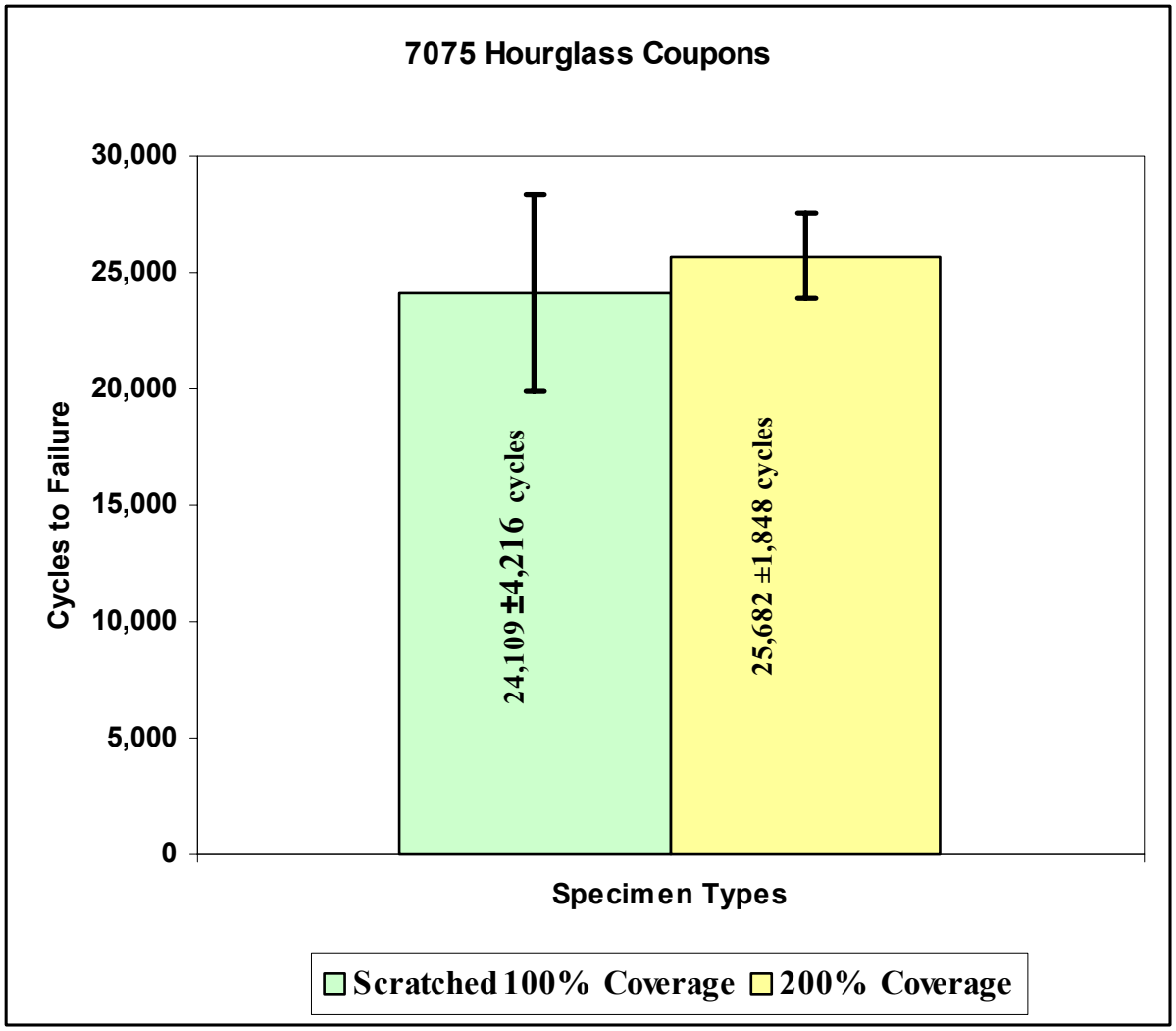
Quantitative results



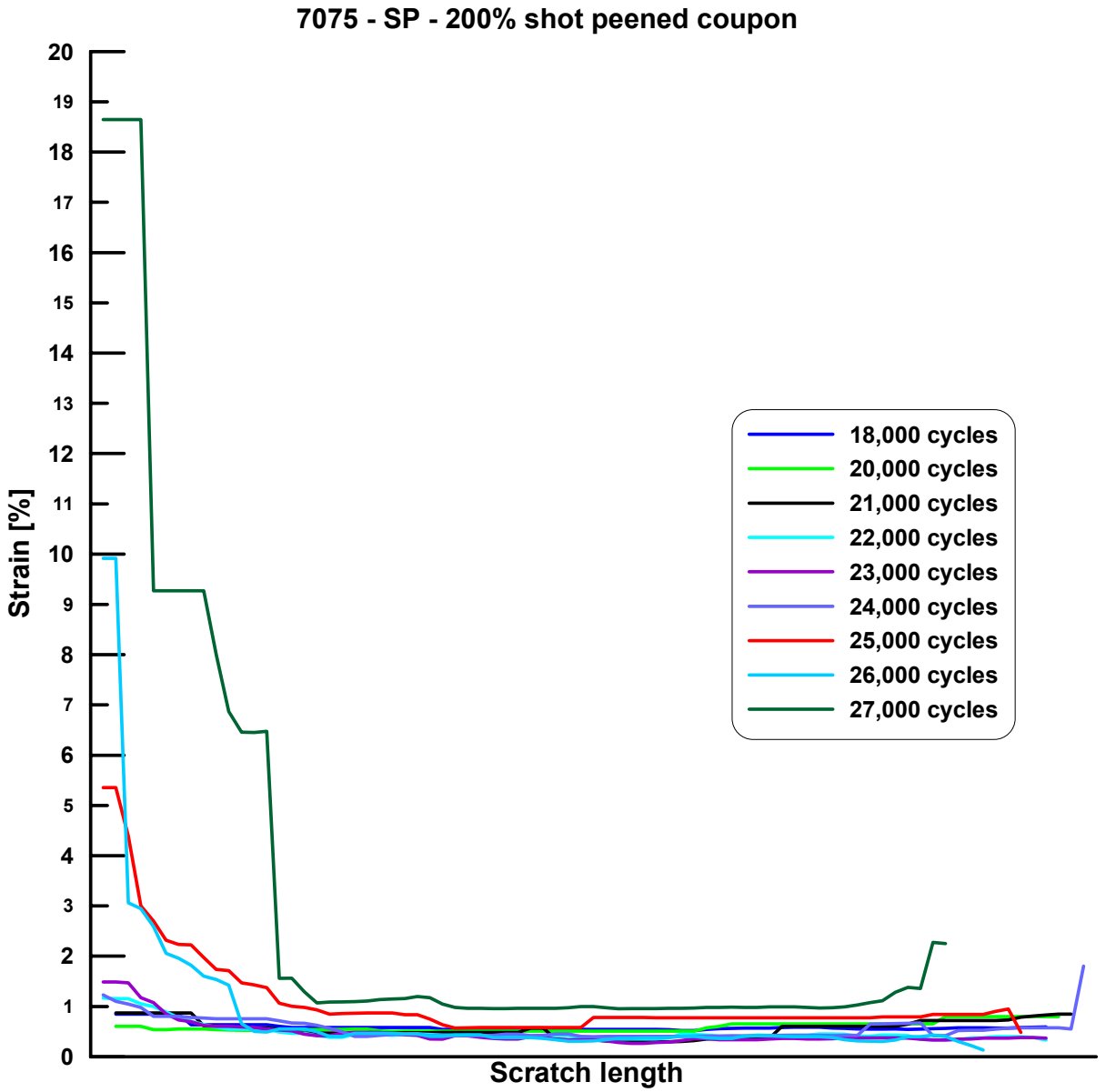
Element	Weight%	Atomic%
C K	9.46	19.60
O K	2.08	3.23
Mg K	1.77	1.82
Al K	78.14	72.08
Cu K	1.88	0.74
Zn K	6.66	2.54
Totals	100.00	

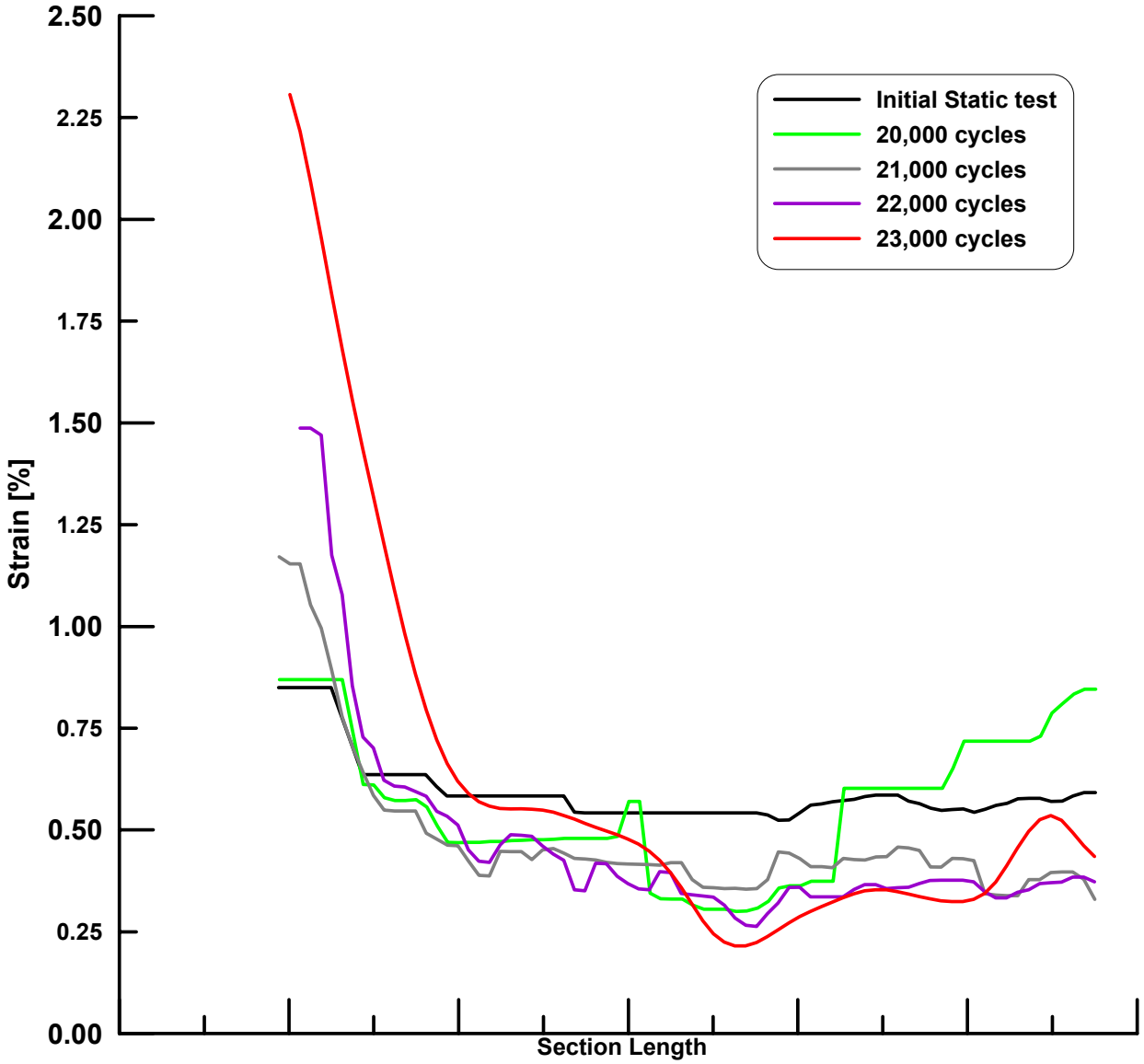
Testing of the hourglass coupons

- Testing at Smax = 45Ksi, R = 0.5 @ 2 Hz
- Shot peened coupons failed at less than 40,000 cycles
- The pristine coupons failed at ~ 325,000 cycles (same range as in the Mil-Hdbk data for 7075 at R=0.5)
- Average Scratch depth ~ 265μm (~ 0.01”)


7075 Hourglass Coupons
30,000
25,000
20,000
15,000
10,000
5,000
0
Cycles to Failure
24,109 ±4,216 cycles
25,682 ±1,848 cycles
Specimen Types
Scratched 100% Coverage
200% Coverage

- Aramis to measure the strain field around the notch
  - Initial static test (max load of the fatigue cycle)
  - Static test run after
    - 18,000 cycles
    - 20,000 cycles and then every thousand cycles till failure


7075 - SP - 200% shot peened coupon
Strain [%]
Scratch length
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
18,000 cycles
20,000 cycles
21,000 cycles
22,000 cycles
23,000 cycles
24,000 cycles
25,000 cycles
26,000 cycles
27,000 cycles


2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Strain [%]
Section Length
Initial Static test
20,000 cycles
21,000 cycles
22,000 cycles
23,000 cycles

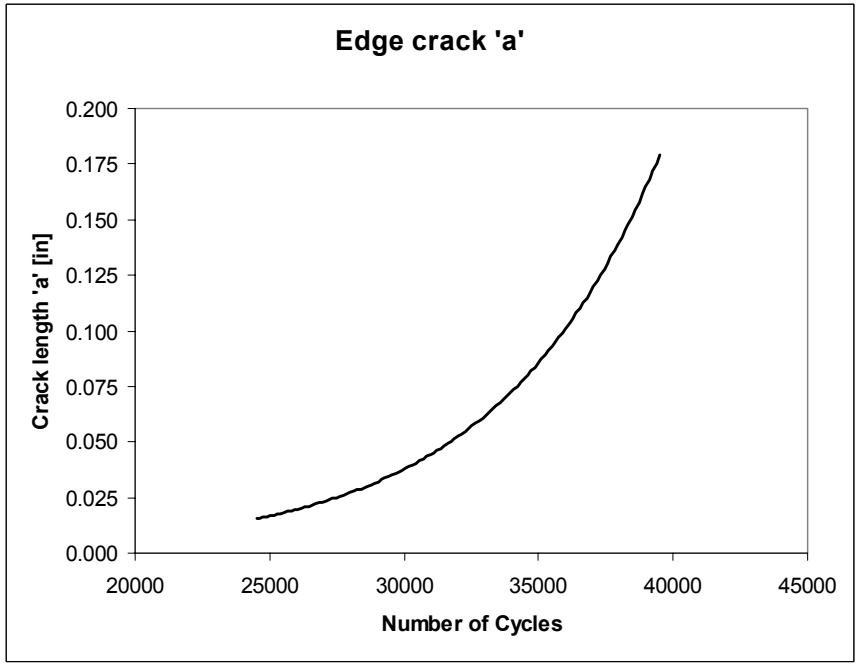
Use of the Eddy current Probe

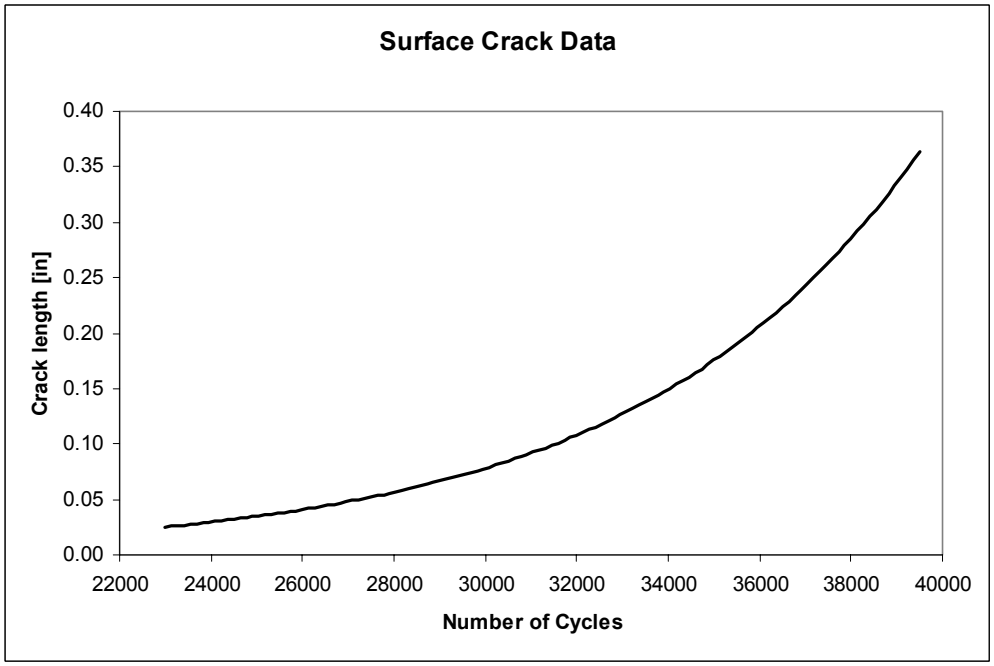
- To determine the onset of cracking Eddy current probes were used
- The specimens were inspected before installing in the machine and then another inspection was made after loading to the maximum load of the fatigue cycle
  - Difficulty in interpreting the signal as the surface had some Fe left from the shot peening
    - The test was paused at several intervals and inspected
    - After the crack was detected the specimen was fatigued till failure
      - The specimens fractured after another 12,500 cycles

Optical Measurements

- The hourglass coupons were monitored using the optical microscope
- The stereoscope is capable of 160X resolution
- The specimens were inspected periodically and the images analyzed using image analysis software
- Once the crack was detected in the specimens, measurements were made every 1,000 cycles

Crack Length Measurements



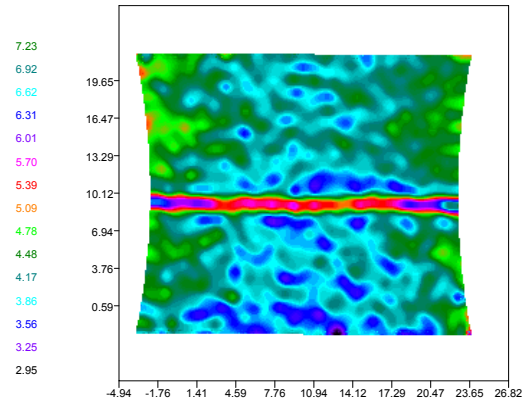


ESPI Method

- Used the Laser Speckle Interferometry to determine the displacement field around the scratch region
  - Similar to the Aramis system but with higher resolution
  - Initial reading was done at maximum load of the fatigue cycle
  - Second reading at 20,000 cycles
  - Subsequent readings at every 1,000 cycles till failure

7075–100% peening coverage

Initial test



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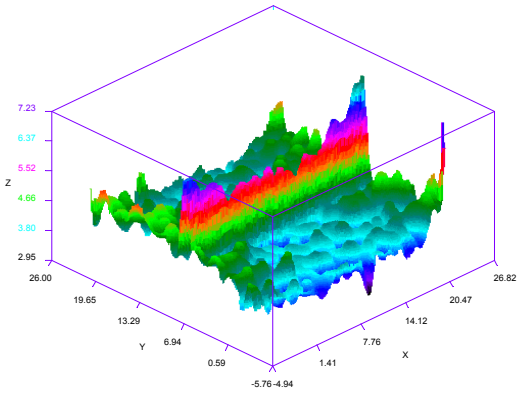
ROTORCRAFT - FAA
7075-SP-2-200pcnt
After 0 Cycles
Y-Strain-00000.TFD

	No.	Load lbf
Reference	0	64.5
Measurement	43	1.13e+004



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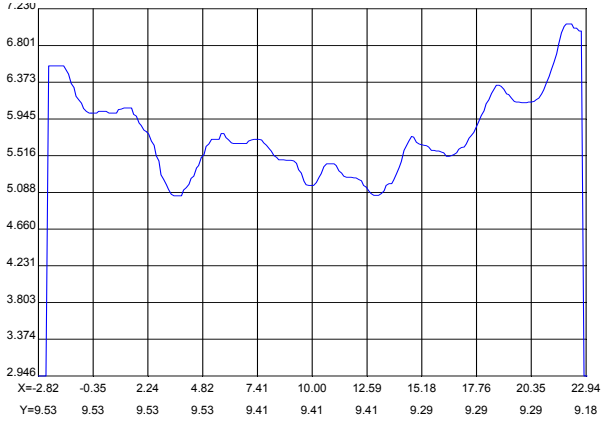
After 00000 Cycles
Y-Strain-00000.TFD

	No.	Load lbf
Reference	0	64.5
Measurement	43	1.13e+004



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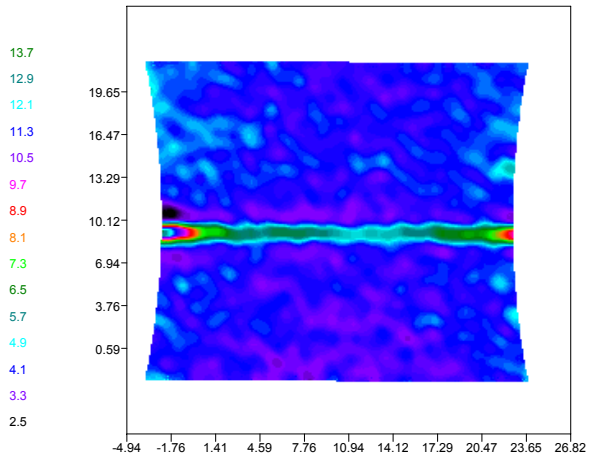
7075-SP-2-200pcnt
After 0 Cycles
Y-Strain-00000.TFD

	No.	Load lbf
Reference	0	64.5
Measurement	43	1.13e+004

- Initial Test
- Y-strain around the notch
- Profile of the strain
- 3-D plot of the strain

20,000 cycles



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After 20000 Cycles
Y-Strain-20000.TFD

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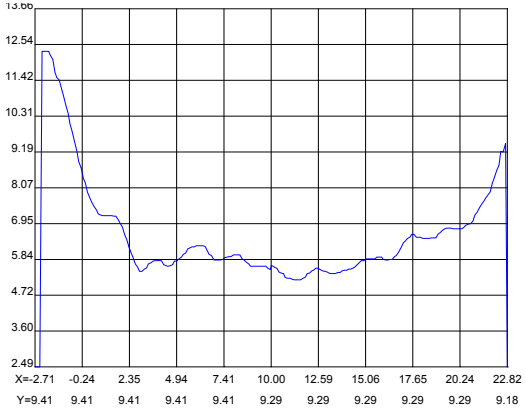
Measurement	41	1.13e+004



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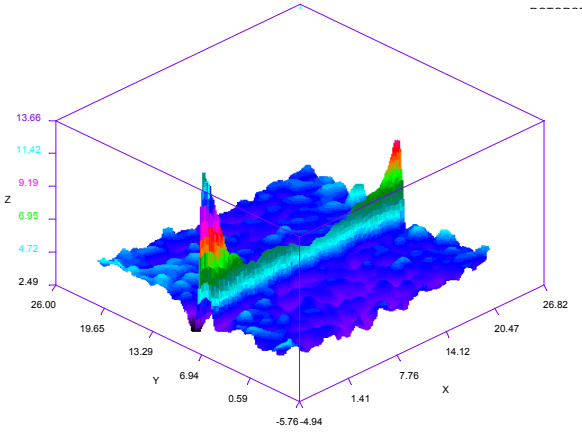
AFT - FAA
100pcnt
) Cycles
000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	41	1.13e+004



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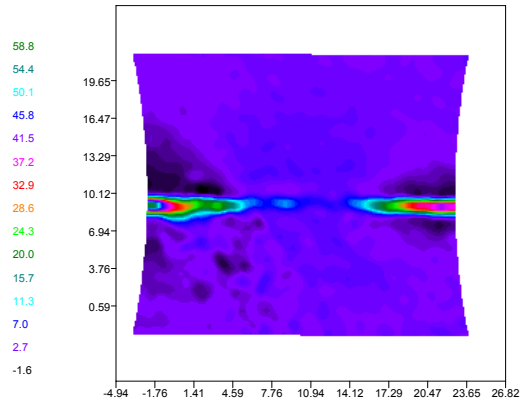
7075-SP-4-100pcnt
After 20000 Cycles
Y-Strain-20000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	41	1.13e+004

27,000 cycles



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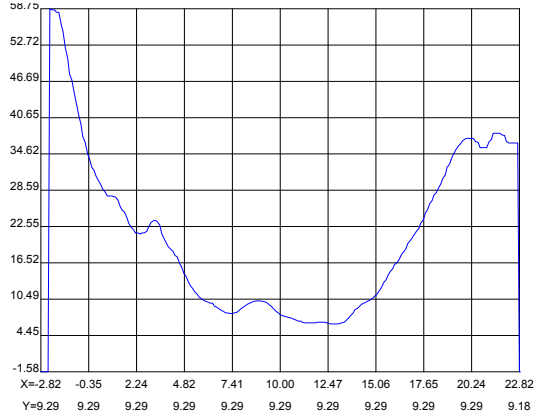
After 27000 Cycles
Y-Strain-27000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	50	1.13e+004



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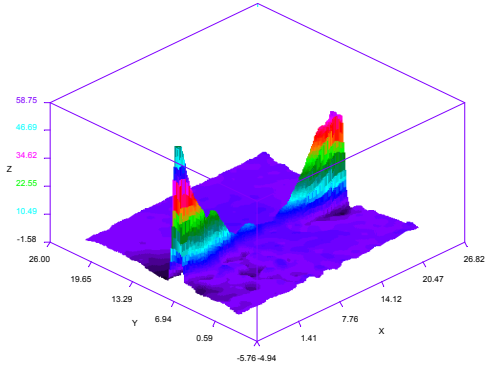
ROTORCRAFT - FAA
7075-SP-4-100pcnt
After 27000 Cycles
Y-Strain-27000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	50	1.13e+004



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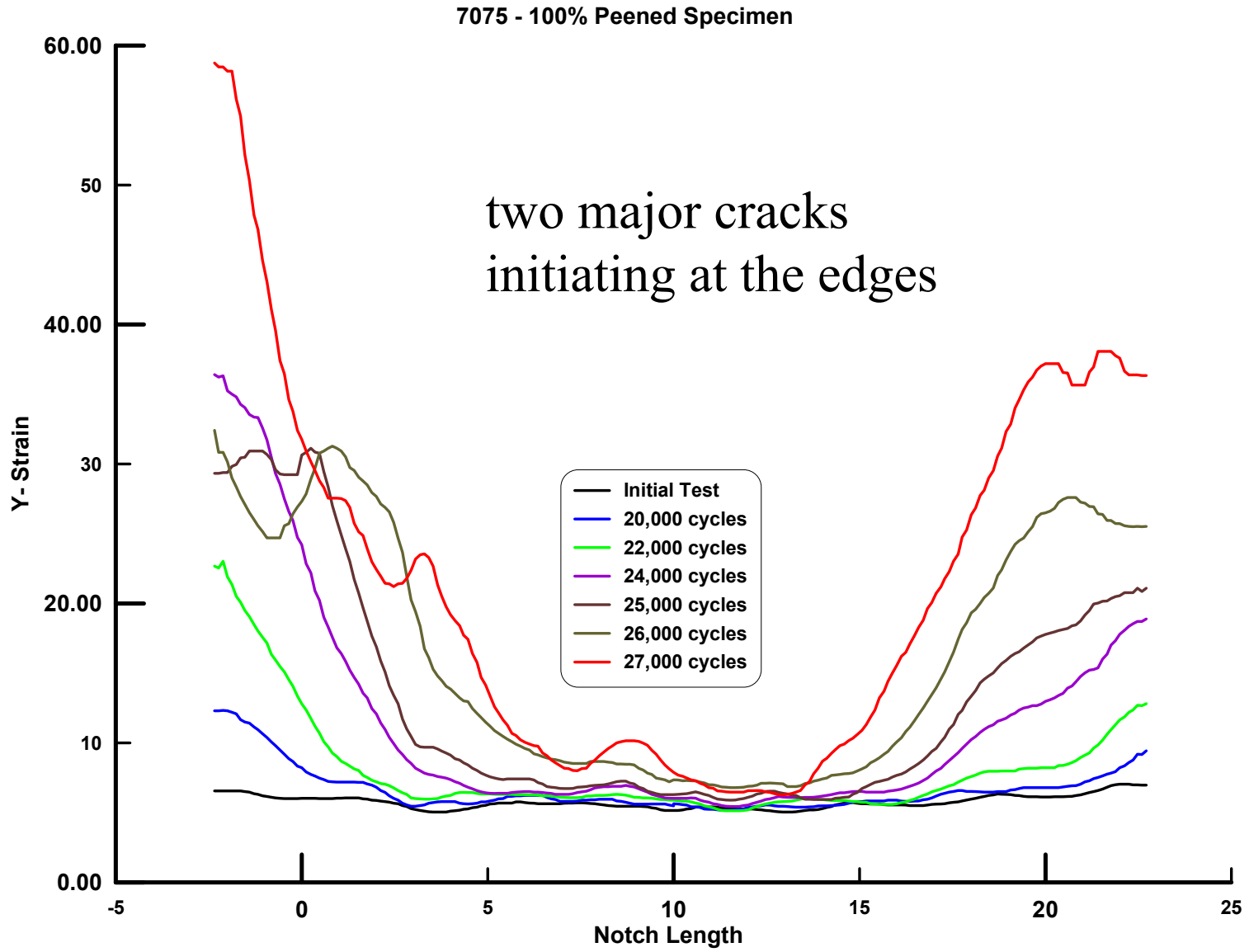
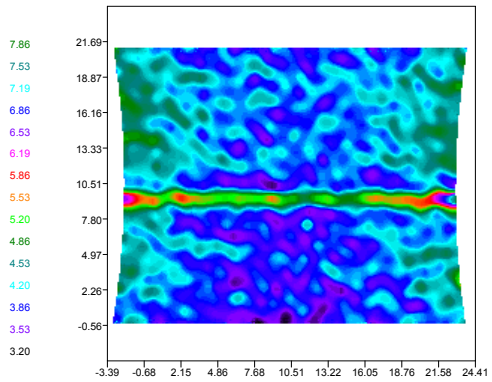
ROTORCRAFT - FAA
7075-SP-4-100pcnt
After 27000 Cycles
Y-Strain-27000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	50	1.13e+004


7075 - 100% Peened Specimen
two major cracks
initiating at the edges
Initial Test
20,000 cycles
22,000 cycles
24,000 cycles
25,000 cycles
26,000 cycles
27,000 cycles
Y- Strain
60.00
50
40.00
30
20.00
10
0.00
-5
0
5
10
15
20
25
Notch Length

7075- 200% coverage
Initial test



PV= 4.663
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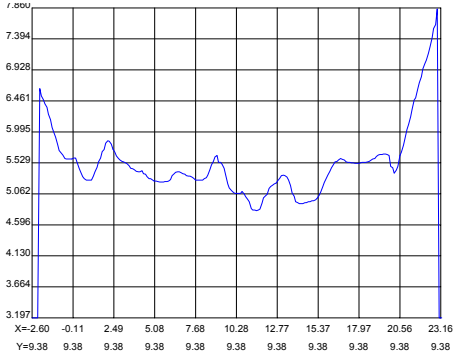
ROTORCRAFT - FAA
7075-SP-2-200pcnt
After 20000 Cycles
Y-fringes-20000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	36	1.13e+004



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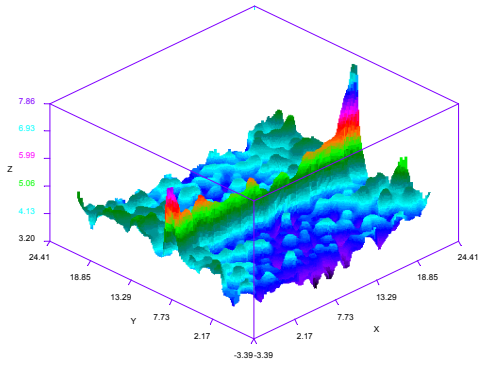
7075-SP-2-200pcnt
After 20000 Cycles
Y-Strain-20000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	36	1.13e+004

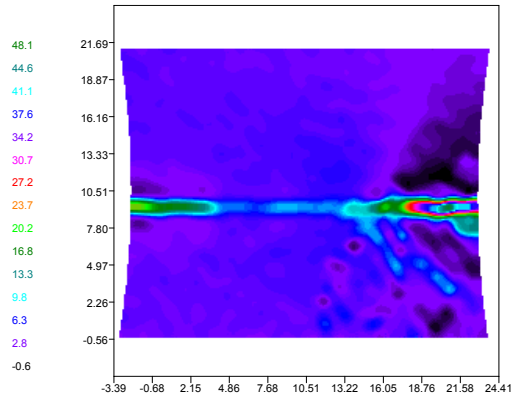


PV= 4.663
28-11-2004 17:46:32
ROTORCRAFT - FAA
7075-SP-2-200pcnt
After 20000 Cycles
Y-Strain-20000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	36	1.13e+004

- Initial Test
- Y-strain around the notch
- Profile of the strain
- 3-D plot of the strain

34,000 cycles



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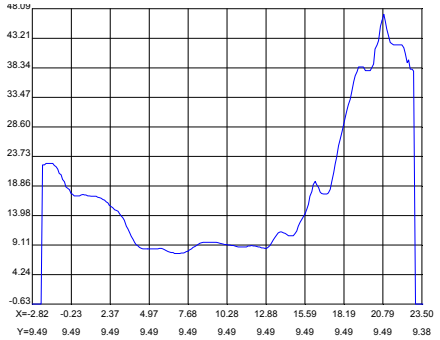
ROTORCRAFT - FAA
7075-SP-2-200pcnt
After 34000 Cycles
Y-fringes-34000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	41	1.13e+004



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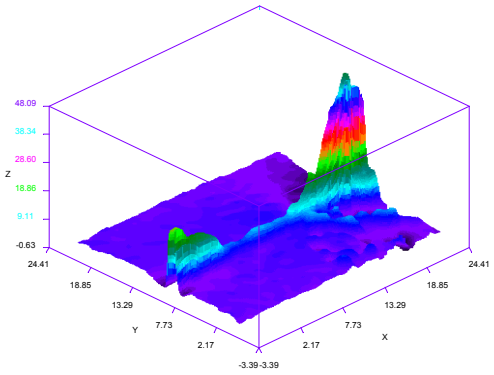
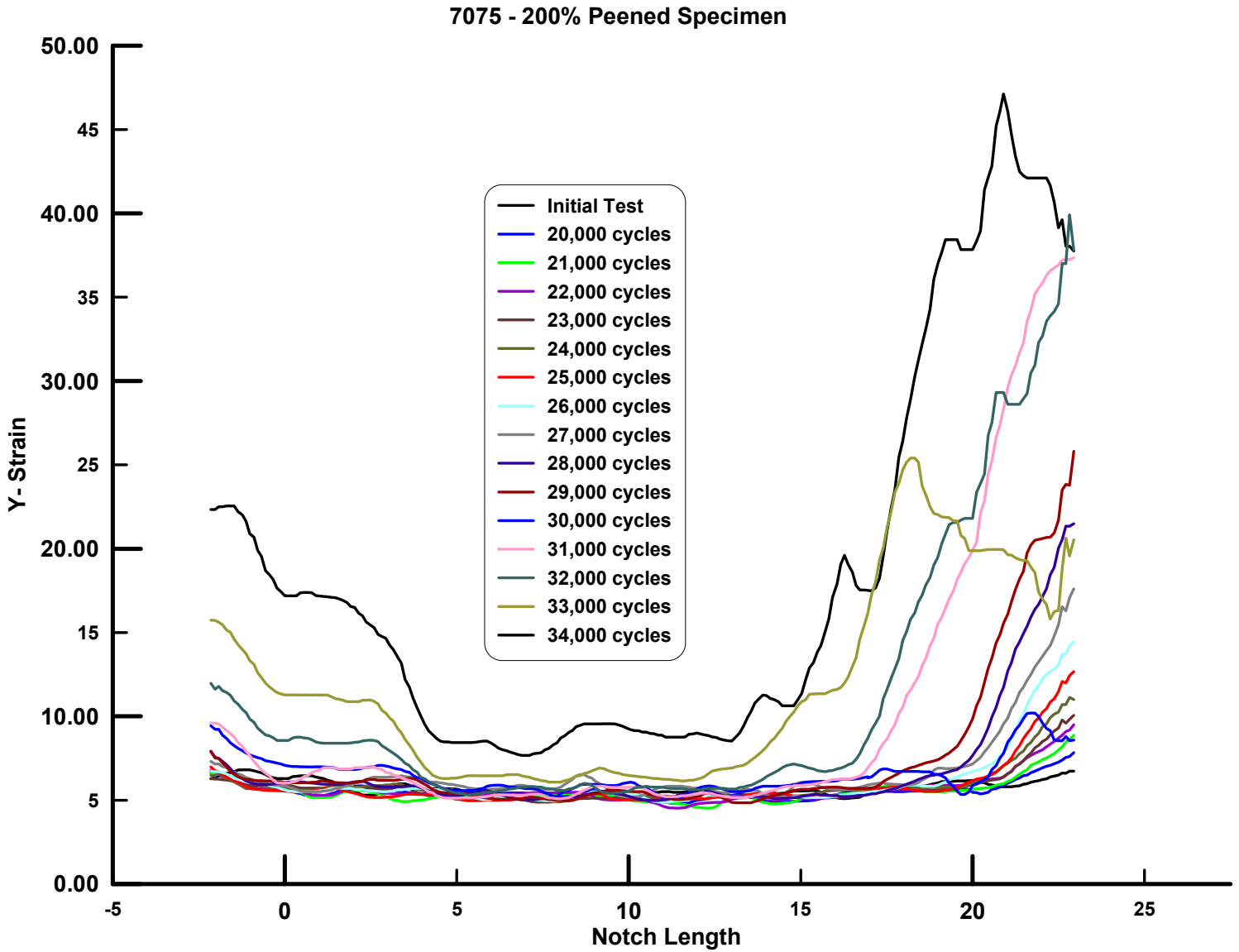
ROTORCRAFT - FAA
7075-SP-2-200pcnt
After 34000 Cycles
Y-Strain-34000.TFD

No.		Load lbf
Reference	0	32.2
Measurement	41	1.13e+004



PV= 48.717
28-11-2004 20:05:14
ROTORCRAFT - FAA
7075-SP-2-200pcnt
After 34000 Cycles
Y-Strain-34000.TFD

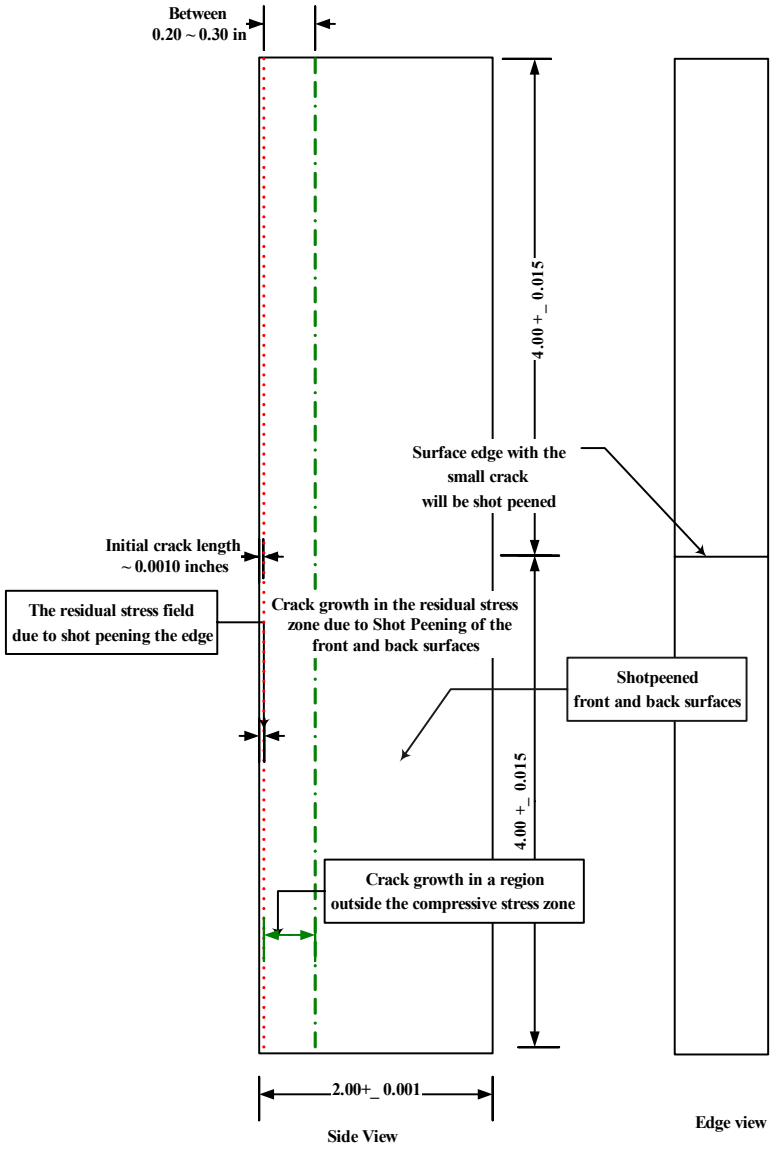
No.		Load lbf
Reference	0	32.2
Measurement	41	1.13e+004


7075 - 200% Peened Specimen
Y- Strain
Notch Length
50.00
45
40.00
35
30.00
25
20.00
15
10.00
5
0.00
-5
0
5
10
15
20
25
Initial Test
20,000 cycles
21,000 cycles
22,000 cycles
23,000 cycles
24,000 cycles
25,000 cycles
26,000 cycles
27,000 cycles
28,000 cycles
29,000 cycles
30,000 cycles
31,000 cycles
32,000 cycles
33,000 cycles
34,000 cycles

Initial Attempts

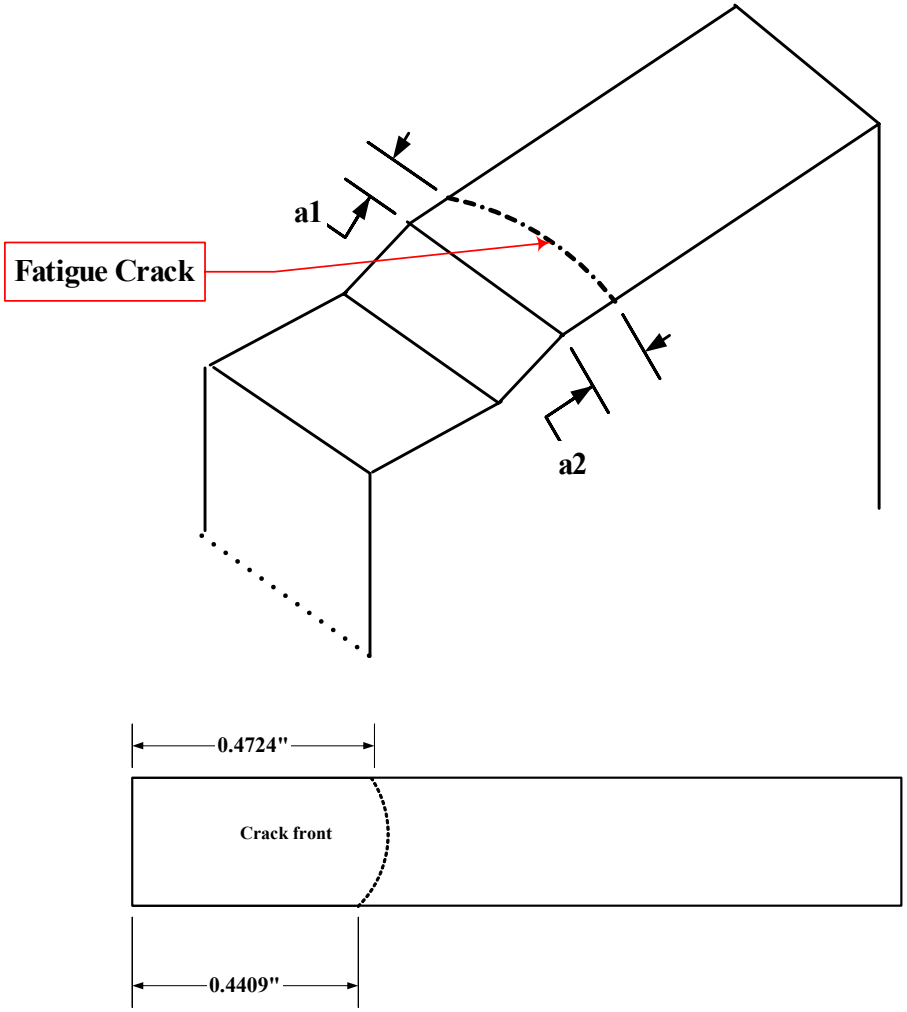
Eccentrically Loaded Single Edge Crack Coupon

- The specimen shape and dimension are shown in the following slide
- The short crack specimen was produced in two steps
  - The ESE (t) coupon was fatigued to generate a specimen of pre-determined crack size
    - Specimen was then machined by removing the material in the wake of the long crack to yield a specimen with crack length of 0.2 ~ 0.3 mm (0.008 ~ 0.012 inches)
    - Initially it was planned to grow the crack to a length of 1.00 inches. It was pointed out that the compressive residual stresses would be so high that it would be difficult to open the crack after machining the wake.
    - At this point it was decided that we would grow the crack for only 0.20 inches.
    - Specimens were tested to until the crack grew for ~ 1.00 and 0.20 inches


Between
0.20 ~ 0.30 in
4.00 +_ 0.015
Surface edge with the
small crack
will be shot peened
Initial crack length
~ 0.0010 inches
The residual stress field
due to shot peening the edge
Crack growth in the residual stress
zone due to Shot Peening of the
front and back surfaces
Shotpeened
front and back surfaces
4.00 +_ 0.015
Crack growth in a region
outside the compressive stress zone
2.00+_ 0.001
Side View
Edge view

- To produce specimens with the crack embedded in the residual stress zone
  - The specimen was to be shot peened on the edge containing the crack
- To study the effect of the crack's interaction with the residual stress field
  - The same specimen can be used

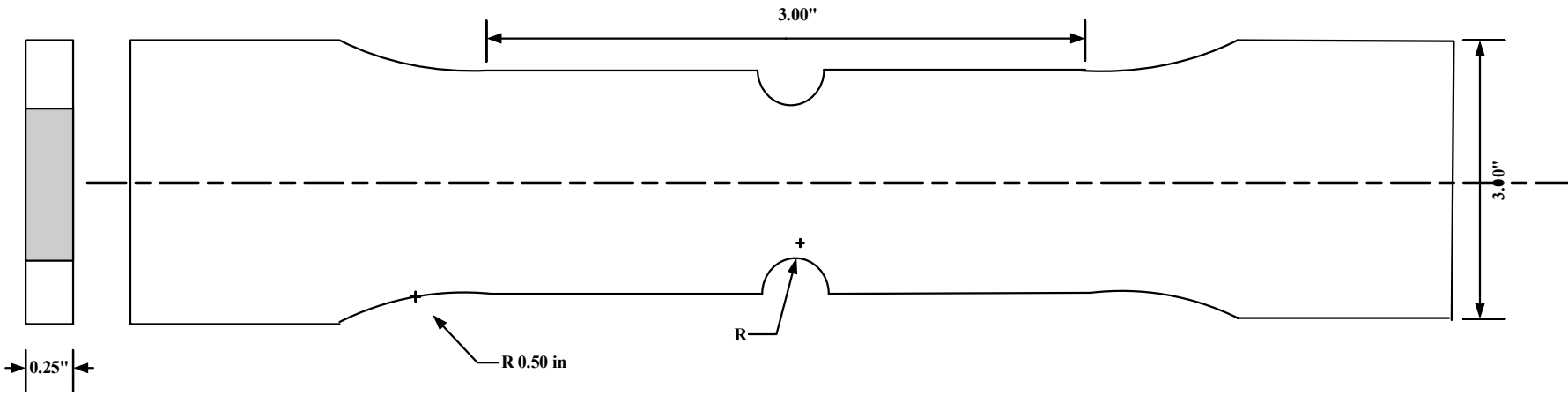
Differences in crack length on the two surfaces



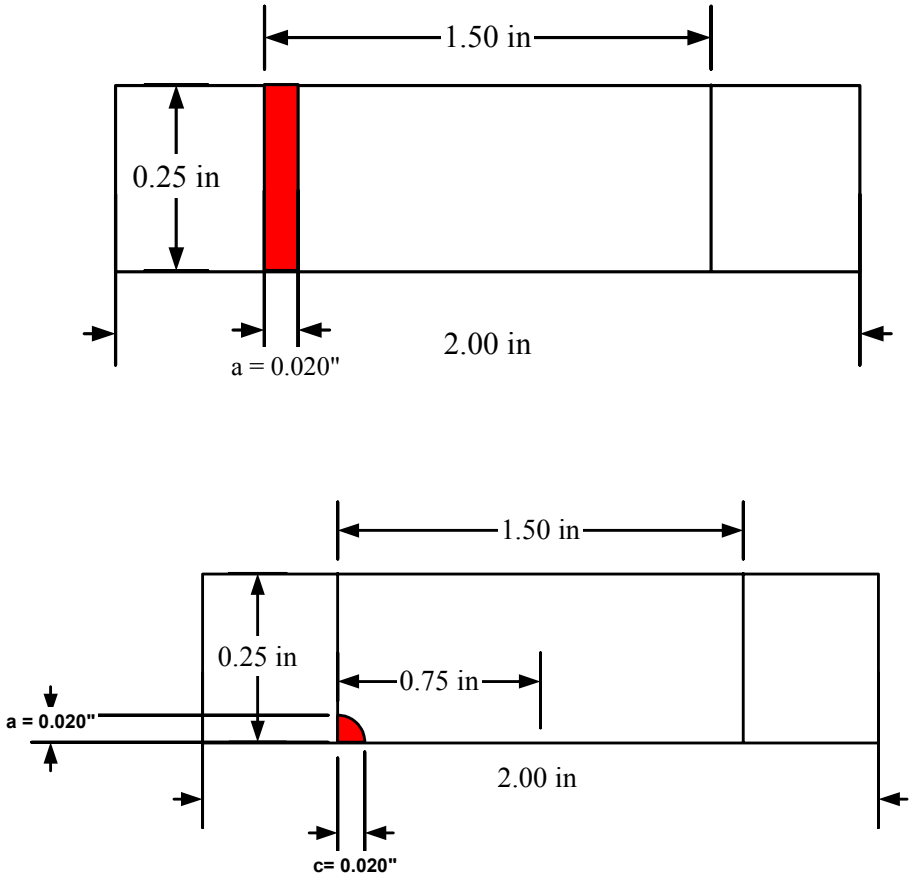
Difference in the length of the crack front on the two surfaces

Specimen Number	Surface 1	Surface 2	Difference in Crack Lengths
	Crack Length [in]	Crack Length [in]	
7075ESE -05	0.54330	0.53540	0.0079
7075ESE -08	0.44090	0.47240	0.0315
7075ESE -06	0.39763	0.42125	0.0236
7075ESE -03	0.45669	0.43700	0.0197
Specimen Number	**Surface 1**	**Surface 2**	**Difference in Crack Lengths**
	Crack Length [in]	**Crack Length [in]**	
7050ESE -01	1.00400	1.00000	0.00400
7050ESE -02	0.92510	0.93300	0.00790
7050ESE -03	0.99210	0.97630	0.01580

Double edge notched specimen



- The double edge notched specimens have been fabricated
- EDM notching will be conducted at Dr. Forman's facility next month
  - Notch using 0.001" diameter wire
  - 'a' = 'c' = 0.020"
  - Grow the fatigue crack and then polish the wake
- ACPD and optical measurements will be made



Through crack and Corner crack configuration

Data for UCI

- Tension test
  - The Young's modulus
  - Poisson's ratio
  - Mass Density of the material
  - Yield Stress
  - Ultimate Tensile Stress
  - Strain corresponding to the Ultimate Tensile stress of the specimen
  - The Stress-Strain Curve for Uniaxial Tension Tests
  - The specimen shape is shown in following Figure
- Parameter's of shot peening
  - radius of the shot
  - the coverage
- Residual stress profile along the depth for both the 100% and 200% coverage in the Al alloys

Tensile Test Data

- Tension test
  - The Young's modulus
  - Poisson's ratio
  - Yield Stress
  - Ultimate Tensile Stress
  - Strain corresponding to the Ultimate Tensile stress of the specimen
  - The Stress-Strain Curve for Uniaxial Tension Tests

- Tensile test were monitored using the following equipment
  - Laser extensometer
    - To provide the total extension of the gage section
  - Bi-axial Extensometer
    - To determine the Poisson's ratio and axial displacement in the linear region
  - Strain gages
    - Gages capable of measuring 20% strains were used
    - 0° and 90° were used results verified with the Bi-axial extensometer

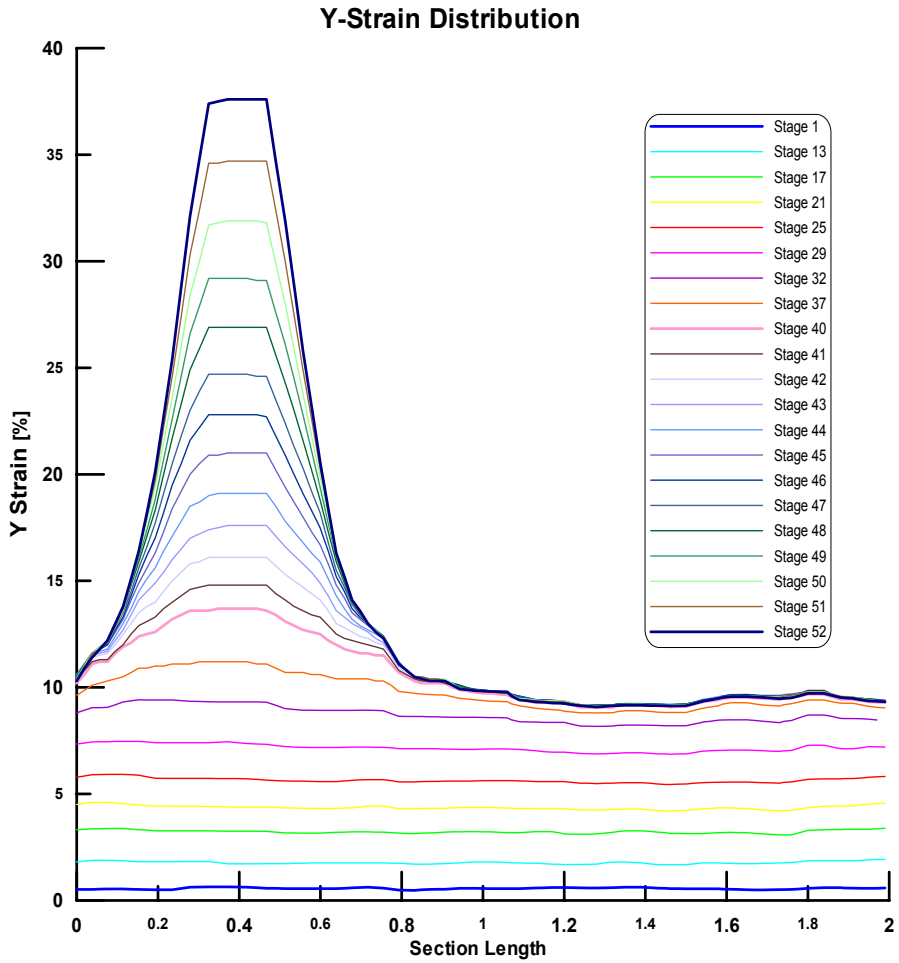
7050 T7451 Static Data

	$\sigma_{ultimate}$ Ksi	$\sigma_{failure}$ Ksi	E Msi	ν	G Length inches	0.2% yield stress	ε %
Average	**75.07**	**61.57**	**10.13**	**0.338**	**0.2937**	**68.69**	**13.6967**
Standard Deviation	**0.319**	**0.568**	**0.0623**	**0.0071**	**0.0152**	**0.444**	**0.7440**
Coefficient of Variation	**0.425**	**0.923**	**0.615**	**2.11**	**5.174**	**0.647**	**5.432**

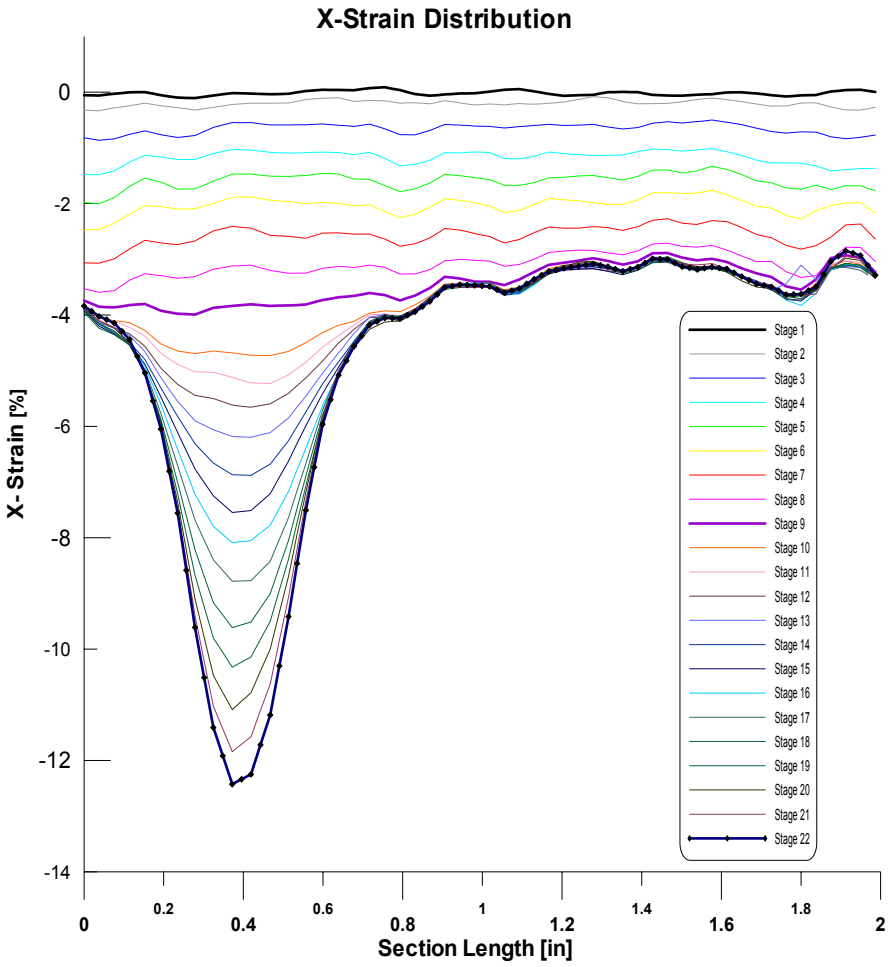
7075 T7351 Static Data

	$\sigma_{ultimate}$ Ksi	$\sigma_{failure}$ Ksi	E Msi	ν	0.5% yield stress	ε %
Average	**74.76**	**65.49**	**10.18**	**0.336**	**67.23**	**13.04**
Standard Deviation	**0.768**	**1.037**	**0.1219**	**0.135**	**0.663**	**0.569**
Coefficient of Variation	**1.028**	**1.583**	**1.198**	**4.018**	**0.986**	**4.363**

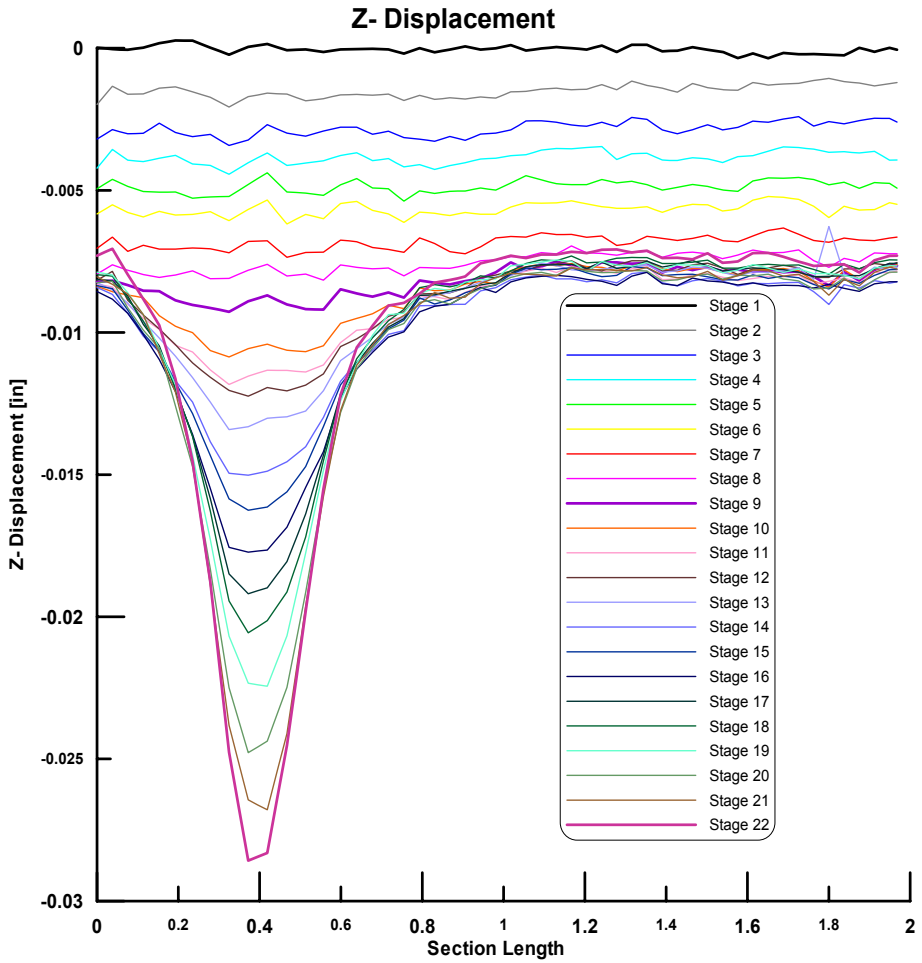
Y-Strain using Aramis



X-Strain using Aramis



Z-displacement using Aramis



Shot Peening

- Intensity used 0.006-0.010A
  - 0.077-0.077A (measured intensity)
- Specification AMS-S-13165
- 100% coverage and 200% coverage
- Shot Diameter – 230 R (0.0230 ± 0.001 inches) Cast Steel
- Nozzle Angle ~ 45°

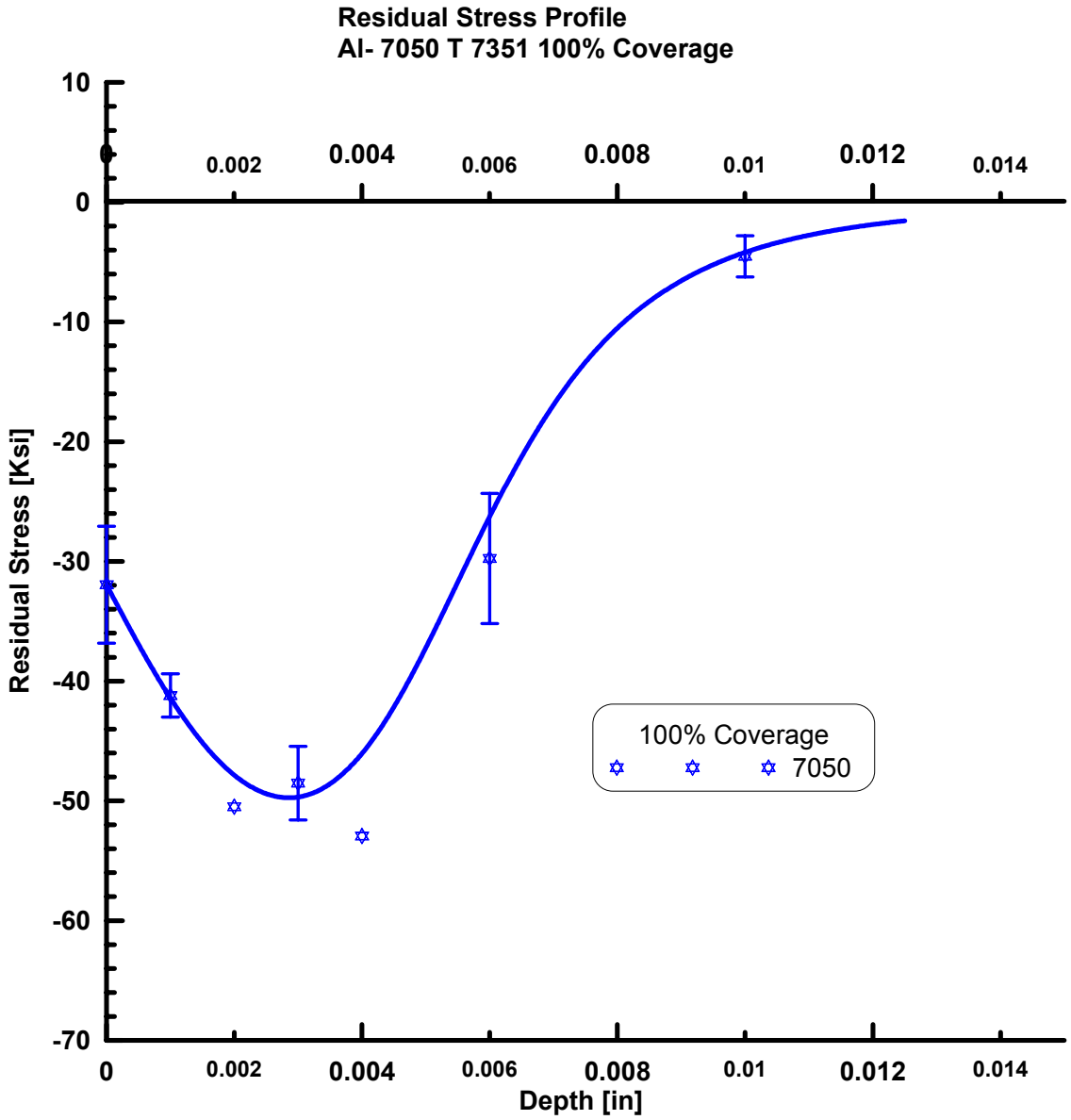
Residual Stress Measurements

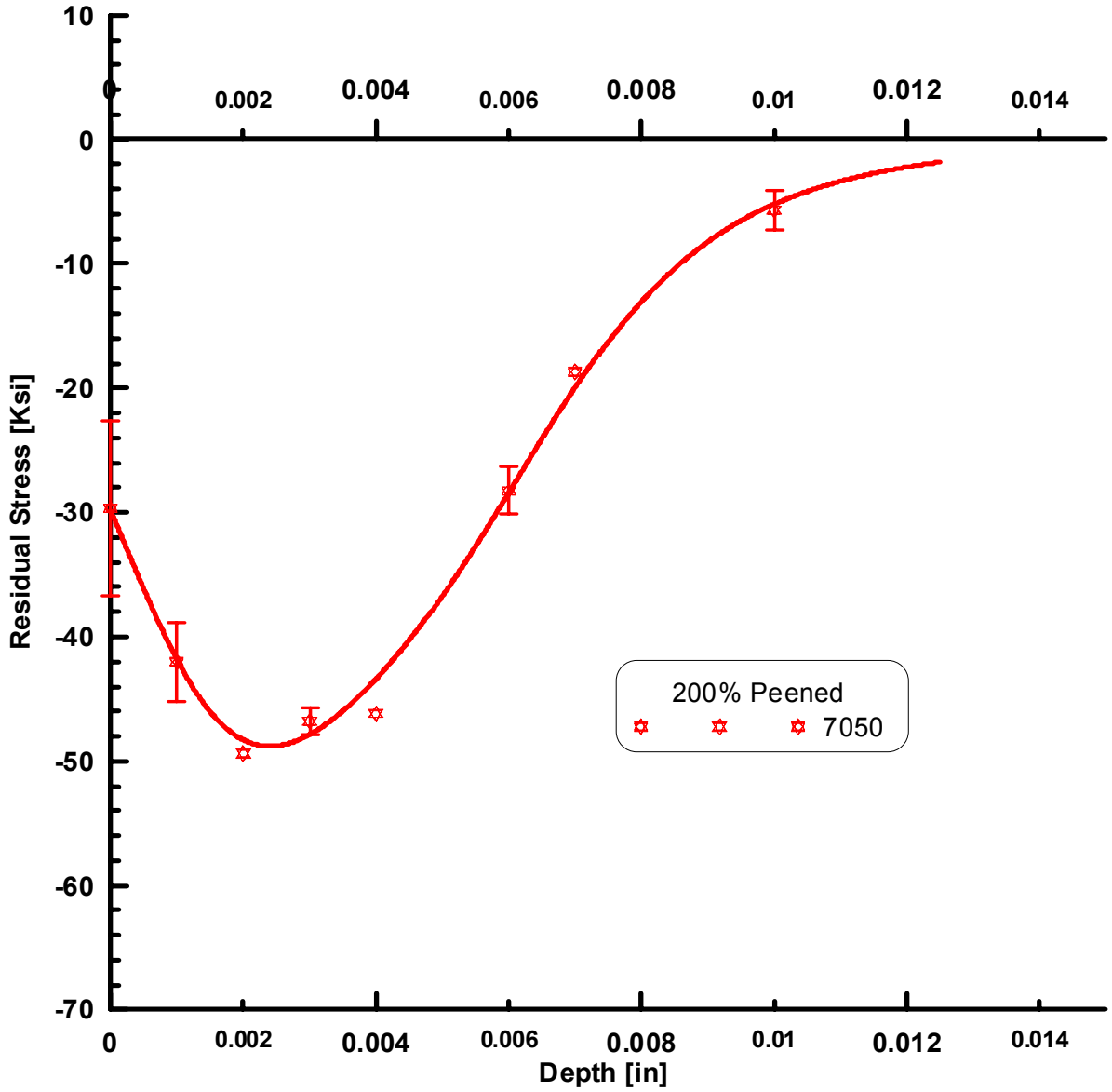
- Results of the 100% coverage Al 7050-T7451
- Total number of specimens 5
- Depths of 0.0020” 0.0040” were measured for one specimen only
- Standard deviation is a measure of variability of the measured stresses at a particular depth among different specimens
- There is an error involved with each measurement, this information is not contained in the residual stress profile plots

Depth [in]	Residual Stress [Ksi]	Std. Dev
0.0000	-31.95	± 4.89
0.0010	-41.19	± 1.80
0.0020	-50.48	
0.0030	-48.52	± 3.07
0.0040	-52.94	
0.0060	-29.75	± 5.44
0.010	-4.52	± 1.72

- Results of the 200% coverage Al 7050-T7451
- Total number of specimens 5
- Depths of 0.0020”, 0.0040” and 0.0070” were measured for one specimen only

Depth [in]	Residual Stress [Ksi]	Std. Dev
0.0000	-29.67	± 6.98
0.0010	-42.04	± 3.15
0.0020	-49.40	
0.0030	-46.82	± 1.07
0.0040	-46.20	
0.0060	-28.26	± 1.90
0.0070	-18.70	
0.010	-5.67	± 1.62


Residual Stress Profile
Al- 7050 T 7351 100% Coverage
Residual Stress [Ksi]
Depth [in]
10
0
-10
-20
-30
-40
-50
-60
-70
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
100% Coverage
7050


Residual Stress Profile
Al- 7050 T 7351 200% Coverage
Residual Stress [Ksi]
Depth [in]
10
0
-10
-20
-30
-40
-50
-60
-70
0.002
0.004
0.006
0.008
0.01
0.012
0.014
200% Peened
7050

Current Status & Future Work

- Hourglass Coupons
  - Testing of the specimens with notch depth 0.010” completed
  - With a scratch of depth .0010 ~ 0.0020” will be conducted after ACPD issues worked out
- Double Notch Specimens
  - Machining of the coupons completed
  - The EDM notching will be performed
  - Replication method will be used for specimens
  - ACPD will also be used
- Tensile testing completed
  - Data generated using Aramis, Laser extensometer and bi-axial extensometer, strain gage
- Residual stress measurement completed

Acknowledgements

- Deep gratitude for the advice provided by Dr Melvin Kanninen in this effort